Scalable swarms of Autonomous Robots and Mobile Sensors

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Objective:

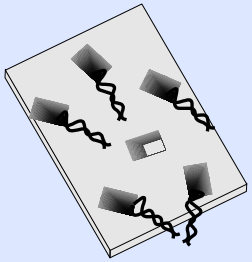
- To catalog, model, analyze collective behaviors in nature;
- To develop abstractions and algorithms for collective systems that are broadly applicable to artificial and natural swarms; and
- To synthesize bio-inspired cooperative control algorithms that enable collective behavior in engineered systems.

Approach:

- Collaborative research with biologists to develop mathematical models and abstractions of collective behaviors;
- Novel systems-theoretic approaches that bridge discrete and continuous mathematics to synthesize controllers and estimators;
- Simulation and experimental platforms to test, validate and demonstrate algorithms for collective behaviors.

Technical Success:

- SWARMS database brings together relevant group behaviors to engineers tactically and functionally
- Fundamental contributions to modeling interactions at different levels in biology - molecules, cells, organisms
- Novel distributed task allocation paradigms with and without communication
- Bio-inspired coverage and exploration algorithms
- Flocking and formation control with sensors and vehicles
- Framework for cooperative manipulation, pursuit
- Engineered swarms developed and demonstrated



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Application / Outcome:

- Workshop on Swarming in Natural and Engineered Systems, 2003, 2005, 2007, 2009 (multiple universities and funding agencies)
- Presentations and publications in professional/DoD conferences and transactions
- Penn's experimental testbed with the *Scarab* and the *Khepri* robots, the software infrastructure, and the design details have been shared with researchers from USMA and the Army Research Laboratory (Aberdeen and Adelphi).
- Penn has hosted multiple visits from USMA and ARL. Penn has established a close working relationship with ARL (Jon Borenstein) and is collaborating with them on the Robotics CTA.
- Berkeley has established a relationship with SOCOM on operational issues pertaining to micro-UAVs.
- Penn has also exchanged many visits with personnel from ARL (Aberdeen/Adelphi), ARDEC (Picatinny Arsenal), TTCP, and NAVAIR (Patuxent, Maryland) and engaged in many discussions on swarming behaviors.

Payoff:

- Utilize sensing, estimation, control and planning algorithms for large groups that are decentralized, based only on local information, and independent of identities of individuals;
- Enable "wholes" that are bigger than the "sums of the parts"
- Realize large resilient, adaptive and secure teams of unmanned and inexpensive vehicles.
- Develop Asymmetric Broadcast Control (ABC) - architecture for controlling swarms of vehicles and sensors
- Develop novel distributed task allocation paradigms with and without communication
- Develop bio-inspired coverage and exploration algorithms
- Develop flocking and formation control with sensors and vehicles
- Develop framework for cooperative manipulation, pursuit.

Follow on successes:

- Army Research Laboratory Collaborative Technology Alliance (MAST) involving Berkeley, MIT and Penn (3 of the five institutions involved in SWARMS
- SMARTS project, Lockheed Martin. System of Micro Autonomous Robots and Sensors (SMARTS) for ISR
- Networked Autonomous Systems Control (NASC), BAE Systems
- Currently pursuing disclosures and transfer of technology to Emergent Views, Inc. We are also planning a joint demonstration of technology involving multiple cooperating micro UAVs to SOCOM.

Remaining technology gaps:

- To synthesize controllers for micro bio robots that allow them to navigate micro channels with onboard sensing and actuation in collaboration with biologists and experts in micro-fluidics;
- To use techniques from algebraic topology to understand and formulate motion coordination problems in a coordinate-free setting without requiring the use of metric information (i.e., GPS-like sensors);
- To integrate discrete auction-like coordination algorithms with continuous motion control algorithms using a hybrid systems framework that lends itself to controllers with global performance guarantees;
- To develop territory partitioning algorithms via minimal, unreliable, sporadic peer-to-peer communication, and a systematic approach to solving coverage and coverage-verification problems with swarms;
- To establish a framework, the algorithms and experimental testbeds for three-dimensional swarming that will facilitate the transition of technologies to the Army.